JACC Vol. 11, No. 5
May 1988:925–9

Relations of Preoperative Hemodynamics and Coronary Blood Flow to Improved Left Ventricular Function After Valve Replacement for Aortic Regurgitation

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In this study of the limits of reversibility of left ventricular function after aortic valve replacement for aortic regurgitation, measurements were made of pre- and postoperative coronary blood flow and left ventricular volumes. Eighteen patients who had undergone aortic valve replacement for pure aortic regurgitation using the Björk-Shiley valve or the Bicerval valve were restudied an average of 8 ± 3 months after surgery.

Postoperative left ventricular end-systolic and end-diastolic volumes returned to near normal values. The slight left ventricular wall thickening apparent before surgery remained unchanged after surgery and, consequently, left ventricular mass, though somewhat reduced, remained abnormally high. Ejection fraction, which was low preoperatively, returned to normal postoperatively. Total coronary sinus blood flow decreased after surgery, but coronary sinus blood flow per 100 g of left ventricular mass increased. This recovery of coronary flow per unit mass was believed to cause the improvement in left ventricular function.

A significant correlation was found between postoperative systolic function and preoperative left ventricular end-systolic and end-diastolic volumes, wall thickness and, especially, left ventricular mass, the latter indicating that, if preoperative left ventricular mass is <350 g/m^2, postoperative improvement of systolic function is attainable. Another significant correlation was indicated by measurements of coronary sinus blood flow per 100 g of left ventricular mass. If this is >35 ml/min before surgery, a postoperative improvement in systolic function to within the normal range may be expected.

(J Am Coll Cardiol 1988;11:925–9)

In aortic regurgitation, it has recently been acknowledged (1–5) that, even when surgery is performed, there are limitations to the postoperative improvement in left ventricular function. The determining factors are thought to involve irreversible degeneration of the myocardium or an imbalance between coronary blood flow and the degree of myocardial hypertrophy. Accordingly, the purpose of this study was to clarify the postoperative improvement of left ventricular function and the limits thereof. This involved measuring coronary sinus blood flow, using the continuous thermodilution method and correlating it with pre- and postoperative hemodynamics.

Methods

Study patients. The subjects were 18 patients who had undergone aortic valve replacement for pure aortic regurgitation at a mean age of 40 ± 10.8 years. The prosthetic valve employed was a tilting disc valve, either the Björk-Shiley or the Bicer-val valve. Patients were examined an average of 8 ± 3 months after surgery. Signed consent was obtained before and after surgery.

Hemodynamic measurements. Right and left heart catheterization was carried out with the patient at supine rest both before and after surgery. Left ventricular catheterization was accomplished by the Seldinger method preoperatively; postoperatively, it was achieved transseptally (6).

The left ventriculogram was taken in the right anterior oblique position by cineangiocardiography, and left ventri-

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Manuscript received June 29, 1987; revised manuscript received September 16, 1987, accepted November 18, 1987.

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0735-1097/88/$3.50

JACC Vol. 11, No. 5
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Table 1. Volumetric Data in 18 Patients Undergoing Valve Replacement for Aortic Regurgitation

	LVESV (ml/m²)		LVEDV (ml/m²)		h (cm)		LVM (g/m²)		EF	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Mean ± SD	181 ± 101	56 ± 44	304 ± 121	123 ± 41	1.3 ± 0.3	1.3 ± 0.3	333 ± 170	203 ± 116	0.43 ± 0.10	0.59 ± 0.18
p value	<0.01		<0.01		NS		<0.01		<0.01	

EF = ejection fraction; h = left ventricular wall thickness; LVEDV = left ventricular end-diastolic volume; LVESV = left ventricular end-systolic volume; LVM = left ventricular mass; NS = not significant; Post = postoperative; Pre = preoperative; SD = standard deviation.

cular volume was calculated by the area-length method (7,8). Left ventricular mass was calculated according to the method of Rackley et al. (9).

Coronary sinus blood flow measurement. This was carried out by introducing a Webster catheter into the coronary sinus by way of the left or right antecubital vein and using a continuous thermodilution method (10,11). The catheter position was confirmed before and after surgery by visualization after injection of contrast medium. Assuming that coronary sinus blood flow reflects the coronary blood flow in the left ventricle (12), coronary sinus blood flow per 100 g of left ventricular mass was calculated on the basis of left ventricular mass determined from the left ventriculogram.

Statistics. The results were expressed as the mean ± standard deviation. The paired *t* test was conducted for the comparison of pre- and postoperative values. Although volumetric data were analyzed in all 18 patients, coronary sinus blood flow data that could be matched and analyzed before and after surgery were available for only 9 patients.

Results

Hemodynamics. Pre- and postoperative data are shown in Tables 1 and 2. Left ventricular end-systolic volume decreased from a mean of 181 ± 101 ml/m² before surgery to 56 ± 44 ml/m² after surgery ($p < 0.01$). Left ventricular end-diastolic volume also decreased significantly from 304 ± 121 ml/m² before surgery to 123 ± 41 ml/m² after surgery ($p < 0.01$), both declining to near normal levels. No significant change was noted in left ventricular wall thickness (mean 1.3 ± 0.3 cm before and after surgery). Mean preoperative left ventricular mass was 333 ± 170 g/m², decreasing significantly to 203 ± 116 g/m² postoperatively ($p < 0.01$). However, because the slight thickening of left ventricular wall thickness seen preoperatively showed no decrease after surgery, left ventricular mass, though somewhat reduced, still showed abnormally high values postoperatively. Ejection fraction increased from 0.43 ± 0.10 preoperatively to 0.59 ± 0.18 postoperatively ($p < 0.01$).

Coronary sinus blood flow. Total coronary sinus blood flow values, which were high before surgery, decreased significantly from 184 ± 23 to 146 ± 25 ml/min after surgery ($p < 0.01$). Neverthelesss, coronary sinus blood flow per 100 g of left ventricular mass and coronary sinus blood flow per 100 g of left ventricular mass per beat each increased significantly because of a postoperative decrease in left ventricular mass of approximately 50%.

Predictive value of preoperative hemodynamic indexes. The relation between postoperative ejection fraction and preoperative left ventricular end-systolic and end-diastolic volume indexes, left ventricular wall thickness and left ventricular mass was also investigated to examine whether there are limiting boundaries in these various preoperative indexes that might be useful in predicting postoperative improvement in systolic function. All of these indexes showed a significant correlation with postoperative ejection fraction (Fig. 1). One of the four patients with a preoperative ejection fraction <0.35 showed a near normal postoperative recovery in systolic function, with an ejection fraction of 0.58. The preoperative left ventricular end-systolic and end-diastolic volume indexes in this patient were much higher than values in patients with a preoperative ejection fraction >0.35. However, some patients showed poorer recovery of postoperative ejection fraction than did this patient, even though they had lower preoperative left ventricular end-systolic and end-diastolic volume index values. Thus, it cannot be said that these indexes of volume are appropriate as indicators of postoperative recovery of sys-

Table 2. Coronary Sinus Blood Flow in Nine Patients Undergoing Valve Replacement for Aortic Regurgitation

	CSF (ml/min)		CSF/LV (ml/min per 100 g LV)		CSF/LV per HR (ml/beat per 100 g LV)	
	Pre	Post	Pre	Post	Pre	Post
Mean ± SD	184 ± 23	146 ± 25	38 ± 12	56 ± 19	0.51 ± 0.16	0.68 ± 0.21
p value	<0.01		<0.01		<0.01	

CSF = coronary sinus blood flow; CSF/LV = coronary sinus blood flow per 100 g of left ventricular mass; CSF/LV per HR = coronary sinus blood flow per 100 g of left ventricular mass per beat.

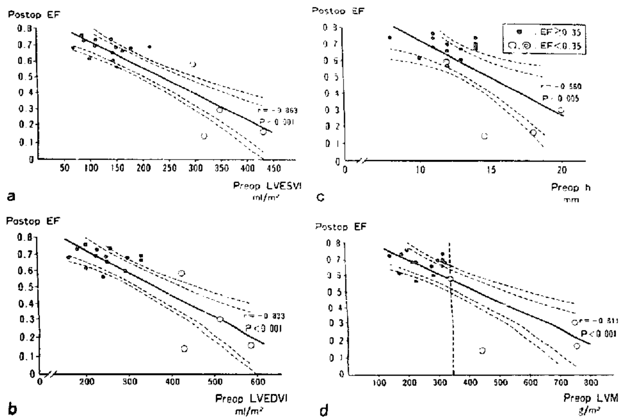


Figure 1. Hemodynamic measurements in 18 patients. The **closed circles** indicate a preoperative (Preop) ejection fraction (EF) >0.35, and the **single and double open circles** indicate a preoperative value <0.35. The four patients with a preoperative ejection fraction <0.35 (**a** and **b**) showed much higher preoperative left ventricular end-systolic volume index (LVESVI) and end-diastolic volume index (LVEDVI) than did patients with a preoperative ejection fraction >0.35. In contrast, left ventricular wall thickness (h) in one of the patients who exhibited a postoperative (Postop) improvement in ejection fraction (indicated by a **double open circle**) showed no difference compared with the other patients (indicated by a **closed circle** [**c**]). The postoperative ejection fraction values were normal in patients in whom preoperative left ventricular mass (LVM) was <350 g/m², including one patient indicated by a **double open circle** (**d**). Thus, left ventricular mass appears to be an index of postoperative systolic functional recovery.

tolic function. If one considers left ventricular wall thickness in the patient with a preoperative ejection fraction <0.35 in the same way, the preoperative value of 12 mm was no different from that in other patients. In contrast, left ventricular mass <350 g/m², as indicated by its relation to left ventricular end-diastolic volume and left ventricular wall thickness, was associated with an improved postoperative ejection fraction, as was also shown in this patient. Furthermore, other patients showing a greater decrease in ejection fraction had an abnormally high preoperative value for left ventricular mass. Accordingly, it may be said that left ventricular mass is an index of postoperative systolic functional recovery.

Coronary sinus blood flow versus ejection fraction. With regard to the relation between ejection fraction and coronary sinus blood flow per myocardial unit mass, both coronary sinus blood flow and ejection fraction showed low preoperative values and both increased postoperatively (Fig. 2). In addition, a significant correlation was found ($r = 0.813$, $p < 0.01$) between preoperative coronary sinus blood flow per 100 g of left ventricular mass and postoperative ejection fraction (Fig. 3). Thus, the greater the coronary sinus blood flow per unit mass before surgery, the better the recovery of left ventricular function after surgery. If the preoperative coronary sinus blood flow per 100 g of left ventricular mass is >35 ml/min, an ejection fraction value of approximately 0.6 may be expected after surgery.

Discussion

There has been some argument as to whether impaired left ventricular function due to aortic regurgitation is improved by surgery (13–17). Reports (1–5) acknowledging the limitation in left ventricular functional improvement after surgery are increasing. To ascertain whether any preoperative factors were responsible for this limitation, we considered the relation between postoperative systolic function and preoperative hemodynamics and coronary blood flow.

Relation between systolic function and left ventricular volume, wall thickness and mass. Henry et al. (1) reported a 69% mortality rate during or after surgery in patients with a

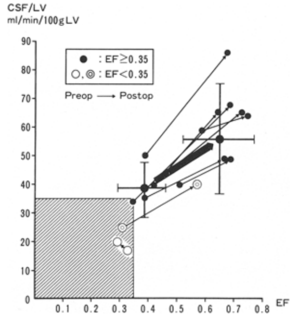


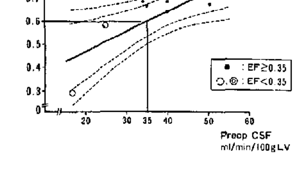
Figure 2. Relation between coronary sinus blood flow (CSF) per myocardial unit mass and the pre- and postoperative changes in ejection fraction (EF). The values of both coronary sinus blood flow per 100 g of left ventricular (LV) mass and ejection fraction were low preoperatively, and both increased postoperatively.

preoperative end-systolic dimension >55 mm and fractional shortening <25% as determined from echocardiographic measurements. It is possible, however, that the problem in their study was one of myocardial preservation during surgery because a cardioplegic solution was used in only a few patients. On the other hand, Fioretti et al. (18) reported that patients in whom myocardial protective solution was used did not have a poor prognosis, even when end-systolic dimension was >55 mm and fractional shortening <25 %. A poor prognosis can probably be predicted if a decrease in systolic function occurs in association with factors indicating increased left ventricular chamber size due to volume overload. Borow et al. (4), studying the relation between postoperative fractional shortening obtained by echocardiography and values of preoperative left ventricular end-systolic and end-diastolic volume indexes obtained by cineangiocardiography, reported a favorable inverse correlation, especially in the case of left ventricular end-systolic volume index. Although we also believed that there was a relation between postoperative systolic functional recovery and left ventricular end-systolic and end-diastolic volume indexes and left ventricular wall thickness and mass, much more importance was attached to the factor of left ventricular mass; we predicted a better postoperative systolic functional recovery if the postoperative left ventricular mass was <350 g/m^2. Because the left ventricular volume reflects the degree of regurgitation, and left ventricular wall thickness the period of illness, it is believed that a combination of these factors may represent the myocardial mass.

Prognostic role of coronary blood flow. When volume overload is alleviated by means of surgery, there is a marked reduction in the size of the left ventricle. However, because there is no reduction in left ventricular wall thickness postoperatively, values for left ventricular mass remain abnormally high despite some postoperative reduction. Because of the increased mass before surgery, there is an increase in myocardial oxygen demand, leading to higher than normal values for total coronary sinus blood flow (19,20). Moreover, when the mass increases, there is a decrease in myocardial flow per unit mass, resulting in a condition of insufficient coronary flow, thereby causing a reduction in systolic function. In contrast, although in our study the total coronary sinus blood flow decreased in association with a marked postoperative decrease in left ventricular mass, there was an increase in coronary sinus blood flow per 100 g of left ventricular mass. This indicates a recovery of the preoperative impaired coronary flow, suggesting that this postoperative increase in coronary flow might be responsible for the postoperative improvement in ventricular systolic function. Accordingly, although the concept of afterload mismatch described by Ross (21,22) is important in postoperative systolic functional improvement, we believe that the postoperative improvement in coronary blood flow is also important. In addition, we believe that there are limitations to the degree of improvement in postoperative coronary blood flow.

Conclusions. It is suggested that the greater the preoperative coronary sinus blood flow per unit left ventricular mass, the better the postoperative recovery of systolic function after aortic valve replacement for aortic regurgitation. A postoperative ejection fraction of approximately 0.6

Figure 3. Relation between preoperative coronary sinus blood flow (CSF) per 100 g of left ventricular mass and postoperative ejection fraction (EF). A significant positive correlation was found between the two values (r = 0.813 and p < 0.01). Thus, the greater the coronary sinus blood flow per 100 g of left ventricular mass preoperatively, the better the recovery of ejection fraction postoperatively. Likewise, if coronary sinus blood flow is >35 ml/min per 100 g of left ventricular mass, a postoperative ejection fraction >0.6 may be expected.



can be expected if the preoperative coronary sinus blood flow per 100 g of left ventricular mass is approximately 35 ml/min.

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